

FIELD OF THE INVENTION AND RELATED ART

Projection exposure apparatuses for semiconductor manufacture should have a good performance for projecting and transferring a circuit pattern of a reticle upon the surface of a wafer at a high resolving power. The resolution for circuit pattern projection may be improved by enlarging the

numerical aperture (NA) of a projection optical system while holding the wavelength of exposure light fixed. Alternatively, it may be improved by using a shorter wavelength of light, for example, using i-line in
5 place of g-line or using short-wavelength light such as a wavelength 248 nm or 193 nm as can be emitted from an excimer laser, for example, or light of synchrotron orbital radiation (SOR).

On the other hand, because of further
10 miniaturization of a circuit pattern, it is required to align a reticle, having such electronic circuit pattern, and a wafer very precisely.

The required precision may be one-third or less of a circuit pattern. For a 1 giga-bit DRAM, for
15 example, if a circuit pattern is based on a 0.18 micron rule, an overlay precision (alignment through the whole exposure region) of 60 nm or smaller may be required.

Furthermore, an overlay inspection system for
20 measuring the overlay precision should have a precision of about 1/10 of the overlay precision. Thus, for a 1 giga-bit DRAM, a precision of 6 nm or smaller may be required.

As an attempt to accomplishing high-precision
25 position measurement, there has been proposed a TIS correction method effective to reduce the influence of a TIS (Tool Induced Shift) which is a detection system

based error factor among various measurement error factors.

Figure 1A illustrates the TIS correction. In this case, as an example of a position detecting pattern, a surface step (level difference) is defined on a silicon wafer 91 through an etching process, whereby a pattern 92 is produced. After completion of an alignment operation, the relative positional relationship between this pattern 92 and a resist image pattern 93, having been printed and developed, is measured. The measurement is made twice, in the TIS correction method. Here, the second time measurement is performed by rotating the wafer 91 by 180 deg. as compared with the first time measurement. For this reason, the first time measured value is called a zero-deg. measured value $\Delta_{0\text{-deg}}$, while the second time measured value is called a 180-deg. measured value $\Delta_{180\text{-deg}}$.

In accordance with the TIS correction method, a value obtainable by subtracting a 180-deg. measured value $\Delta_{180\text{-deg}}$ from a zero-deg. measured value $\Delta_{0\text{-deg}}$ and then by dividing the difference by 2, is used as a measured value Δ_{TIS} correction. Here, a value which is obtainable by adding the zero-deg. measured value $\Delta_{0\text{-deg}}$ and the 180-deg. measured value $\Delta_{180\text{-deg}}$ and then by dividing the sum by 2, is called a TIS.

Most of currently used registration

inspecting systems and alignment detecting systems are based on a bright-field image processing method.

Figure 1B is a schematic view of a main portion of a registration inspecting system (position detecting system) of known type. In this example, a special mark is provided on a wafer. The position detection is performed by producing, through an optical system, an image of that mark on an image pickup device such as a CCD, for example, and by making various signal processing to an electric signal resulting from that image.

More specifically, a mark 2 is produced on a wafer 1 through an etching process, for example. Also, a mark 3 is formed upon that mark 2 through a lithographic process. The registration inspecting system operates to measure the relative positional relation between these marks 2 and 3. A light beam 6 emitted from a halogen lamp 5 is directed through an optical filter 5a and a lens 5b and via a mirror 5c to a fiber 7. The light from the fiber 7 is directed through an illumination system 8, and a polarization beam splitter 9 reflects S-polarized light. The light goes via a relay 12, a mirror 4, a quarter waveplate 10 and an objective lens 11, and it illuminates the two marks 2 and 3 on the wafer 1. The illumination system comprises a lens 8a for collecting light rays from the fiber 7, a stop 8b, a lens 8c for collecting

Reflected light from the two marks 2 and 3 goes back along the path of illumination, and it goes via the objective lens 11, the quarter waveplate 10, the mirror 4 and the relay 12. Since the polarization direction is P-polarized, at this time, the light passes through the polarization beam splitter 9. The light goes via a quarter waveplate 21, and it is directed through an erector 13 to the image pickup surface of a CCD camera 14, whereby images of the two marks 2 and 3 are formed thereon. The images of the two marks 2 and 3 are transformed by the CCD camera 14 into electric signals which are then applied to a computer (computing means) 15. The signals are processed and analyzed by the computer 15, whereby the relative positional relationship between the two marks 2 and 3 is detected.

The imaging performance most required in this optical system is the symmetry of image (mark image). If there is anything that deteriorates the image symmetry in the optical system, a TIS is there.

In this type of detecting systems, the magnification is made high such as 100x, for example, and, in most cases, a region close to the optical axis is used. Thus, the main factors which cause deterioration of the image symmetry are not abaxial aberrations but, rather, they are an eccentric comma

aberration close to the optical axis of an optical system as well as non-uniformness of an illumination system.

In order to meet further increases in the integration density of a semiconductor device, a three-dimensional arrangement of the device structure has been attempted in addition to further miniaturization of the circuit pattern. If the numerical aperture of a projection optical system is enlarged for attaining a higher integration density of a semiconductor device, the depth of focus of the projection optical system is shortened. For this reason, it is very important to polish the surface of a semiconductor device to remove any surface level differences or surface irregularities to improve the flatness, to ensure that a photoresist is applied to a flattened surface to thereby accomplish higher resolution of projection exposure.

Also, polishing an insulative film layer to be provided on a silicon substrate, to assure a uniform thickness film layer thereon is an important factor for uniforming capacity dispersion of among different layers or regulating the "Via Hole" depth.

A chemical mechanical polishing (CMP) method is an example of a flattening method for assuring flatness by removing any surface level differences or surface irregularities of a semiconductor device.

5 Therefore, in the dark-field image processing which is used most frequently and with a good precision, for example, the contrast of a mark image used in the measurement becomes very low, causing degradation of the detection precision.

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It is accordingly an object of the present invention to provide a position detecting system by which, like a phase difference detecting method, a higher contrast is assured while a TIS causal factor is held small, and by which a position detecting mark can be detected stably and with a good precision even

in a process of low surface-level difference such as a CMP process, for example, such that a pattern of a reticle can be transferred to a wafer with a good precision.

5 It is another object of the present invention to provide an exposure apparatus having such position detecting system.

 These and other objects, features and advantages of the present invention will become more
10 apparent upon a consideration of the following description of the preferred embodiments of the present invention taken in conjunction with the accompanying drawings.

15 BRIEF DESCRIPTION OF THE DRAWINGS

 Figure 1A is a schematic view for explaining a TIS correction method.

 Figure 1B a schematic view of an optical arrangement of a registration inspecting system of
20 known type.

 Figure 2 is a schematic view of a position detecting system according to a first embodiment of the present invention.

 Figure 3A is a schematic view for explaining
25 an example of focus under a condition of an interference image that the outside of a mark is bright.

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Figure 3B is a schematic view for explaining an example of focus under a condition of an interference image that the outside of a mark is dark.

5 Figure 4 is a schematic view for explaining signals corresponding to the conditions of interference images that the outside of the mark is bright and that the outside of the mark is dark, as well as a signal corresponding to the difference between these signals.

10 Figure 5 is a schematic view for explaining the principle of a Linnik interference microscope system.

15 Figure 6 is a schematic view for explaining the principle of a Mirau interference microscope system.

Figure 7 is a schematic view of a position detecting system according to a second embodiment of the present invention.

20 Figure 8 is a flow chart of device manufacturing processes, in an embodiment of the present invention.

Figure 9 is a flow chart for explaining details of a wafer process in the procedure of Figure 8.

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DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figure 2 is a schematic view of a main

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portion of a first embodiment of the present invention. In this embodiment, the invention is applied to a registration inspecting system which is incorporated into a step-and-repeat type or step-and-scan type projection exposure apparatus for use in manufacture of semiconductor devices or any other microdevices. While the following description will be made on an example of inspection of registration between two marks, the system may be used as an alignment detecting system for detecting a position of an alignment mark or as a wafer alignment system.

The position detecting system illustrated is arranged so that two alignment marks 2 and 3, each being formed on a wafer 1 with a three-dimensional shape, are illuminated with non-sensitizing light (non-exposure light) such as light from a He-Ne laser (light source) 31, for example, of a wavelength 633 nm with which a photoresist applied to the wafer 1 is not sensitized, wherein the light from the light source is projected through various components to be described later.

Light from these marks 2 and 3 is directed through various components (to be described later) and to a CCD camera 14, such that the positional information on the alignment marks 2 and 3 is observed through the CCD camera 14, on the basis of which the positions of the marks are detected.

On the other hand, in this embodiment, a reticle (first object: not shown in the drawing) having a circuit pattern formed thereon is illuminated with light (exposure light) from a light source which is a component of an illumination system (not shown) of a projection exposure apparatus, such as, for example, light of g-line or i-line from an ultra-high pressure Hg lamp or exposure light of an emission wavelength from an excimer laser. The projection optical system (not shown) serves to project the circuit pattern of the reticle onto the surface of a wafer (second object) 1 with a reduction magnification of 1:5 or 1:10, for example.

The wafer 1 is placed on a wafer chuck, not shown. The wafer chuck is mounted on a θ -Z stage (driving means: not shown), and it serves to attract the wafer 1 onto its chucking surface so that the position of the wafer 1 does not shift against any vibrations. The θ -Z stage is mounted on a tilt stage (not shown), and it serves to move the wafer 1 in a focus direction (a direction of an optical axis of the optical system), upwardly and downwardly.

In the position detecting system shown in Figure 2, an etching pattern mark (mark) 2 is formed on a silicon etching wafer (wafer) 1 through a lithographic process, a development process and an etching process, for example. On the thus provided

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5 Next, the registration inspecting method
(mark position detecting method) in this embodiment,
will be described. This may be applied to detection
of an alignment mark position in an ordinary alignment
process.

Denoted at 33 is a condenser lens for collecting light (incoherent light) from the rotary diffusion plate 32. The light is then reflected by a mirror 6, and it enters a fiber 7. The light emitted from the fiber 7 is collected within an illumination system 8, wherein S-polarized light is reflected by a polarization beam splitter 9 and is then imaged at a point P_2 . Thereafter, the light goes via a relay optical system 12, a mirror 4, a quarter waveplate 10

and an objective lens (projection optical system) 11, in this order, and it illuminates two marks 2 and 3 formed on the wafer 1 surface. The illumination system 8 comprises a lens 8a, a stop 8b, a condenser lens 8c and a mirror 8d. The stop 8b and the point P_2 are placed optically conjugate with each other.

The reflection light from the marks 2 and 3 on the wafer 1 goes back along its on-coming path, via the objective lens 11, the quarter waveplate 10, the mirror 4 and the relay optical system 12, in this order. It is then imaged at the point P_2 and, thereafter, it enters the polarization beam splitter 9. Since the light impinging on the polarization beam splitter 9 is P-polarized light, it passes through the beam splitter 9. Thereafter, it passes through a quarter waveplate 21 and an erector 13 by which it is directed to an image pickup surface of a CCD camera 14. By this, images (mark images) of the two marks 2 and 3 are formed on the image pickup surface.

Next, a reference light for producing an interference image on the basis of the image of the marks 2 and 3 upon the image pickup surface of the CCD camera 14, will be explained.

The P-polarized light passed through the polarization beam splitter, which is of the light from the light source 31 and passed through the illumination system 8, is transformed by a quarter

5 reflected light goes again through the quarter waveplate 22 by which it is transformed into S-polarized light and enters the polarization beam splitter 9. The light which is S-polarized light is reflected by the polarization beam splitter 9.

15 superposed on the reflection image from the mark 2 or
3 of the wafer 1, whereby an interference image is
produced thereon.

20 corresponding signals which are applied to a computer (computing means) 15. The signals are processed by the computer 15, whereby the relative positional relationship between the marks 2 and 3 is detected.

25 image related to the marks 2 and 3 is produced in the manner described above. Thus, in this embodiment, an image of higher contrast than an image obtainable with

ordinary bright-field illumination, can be produced. Further, in this embodiment, a difference between interference images corresponding to two focuses may be taken, by which an image of twice contrast can be produced.

More specifically, these two focuses may be set as those focus positions where, as shown in Figures 3A, 3B and 4, the difference between an output of the CCD camera 14 corresponding to an alignment mark 41 (which corresponds to the top face 2a of the mark 2 of Figure 2) and an output of the CCD camera corresponding to a mark 42 outside the mark 41 (which mark 42 corresponds to the bottom face 2b of the mark 2 of Figure 2), that is, the difference in image intensities of them, becomes largest and also where their signs are opposite to each other. The positions can be determined on the basis of the intensity of reflection light from the mark 41 or 42 as the wafer 1 is moved along the optical axis direction of the optical system.

As an example, it is now assumed that the surface level difference of the alignment mark 41 is equal to $\lambda/4$ which corresponds to $1/4$ of the illumination wavelength λ (633 nm where He-Ne laser is used). Then, the intensity of the interference image of the mark 42 outside the mark 41 becomes highest as the focus is changed and set to a bright interference

condition wherein the optical path difference between the reference light and the mark 42 outside the mark 41 is equal to a product of the illumination wavelength λ by an integer.

5 As regards the alignment mark 41, on the other hand, since the surface level difference is $\lambda/4$, the intensity becomes lowest, to the contrary (that is, if the reflection intensity of the reference light is equal to the reflection intensity from the wafer, 10 the visibility of the interference fringe becomes higher, and the intensity disappears completely). As a result, a pattern (first image) such as shown in Figure 3A is produced.

15 Second, if the focus is changed by $\lambda/4$ from the initial focus, as shown in Figure 3B, the optical path difference between the reference light and the mark 42 outside the mark 41 then becomes equal to a product of the illumination wavelength λ plus $\lambda/4$, corresponding to a dark interference condition. As a 20 result, the intensity of the interference image of the mark 42 outside the mark 41 becomes lowest. On the other hand, as regards the alignment mark 41, since the surface level difference is $\lambda/4$, the intensity becomes highest, to the contrary. As a result, a 25 pattern (second image) such as shown in Figure 3B is produced.

By taking a difference between these two

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images, an image 43 (Figure 4) having a contrast twice
higher than an interference image corresponding to a
single focus, can be produced. In a case where
bright-field illumination which does not need
5 reference light is desired, a shutter 24 (Figure 2)
may be inserted or, alternatively, the quarter
waveplate 22 and the mirror 23 may be omitted.

The structure and function of the present
invention will now be explained in detail, in
10 comparison with interference microscope systems shown
in Figures 5 and 6.

Figure 5 shows a Linnik interference
microscope system wherein one the same as the
objective is used as a reference light to thereby
15 cancel any abaxial aberrations in design. On the
other hand, Figure 6 shows a Mirau interference
microscope system wherein a half mirror is disposed
between an objective and an article to be observed,
such that light reflected by the half mirror is used
20 as a reference light. As regards details of these
interference microscope systems, reference may be made
to "Wave Optics", Hiroshi Kubota, Iwanami Shuppan Co.,
pages 414 and 415.

In the Linnik interference microscope shown
25 in Figure 5, an objective lens L2 the same as an
objective lens L1 is used as a reference light. In
the present invention, as compared therewith, one the

same as an objective is not used. To the contrary, an intermediate image is produced at the mirror 23, and reflection light therefrom is used as a reference light. If there is any TIS described above, such as
5 spherical aberration or comma aberration, in an optical system between an objective and a relay, which are not a common optical system, an interference image produced is shifted by one color such that a sharp interference image is not obtainable.

10 In the present invention, on the other hand, since it is a requisition to remove a TIS, as described, in a bright-field system, a clear or sharp interference image can be produced even where a reference light from an intermediate image is used.

15 As regards the relationship between the incoherence-transformation and the interference image, it has been confirmed by experiments that an interference fringe obtainable at the CCD camera 14 can be observed without speckle. This is because of
20 that an interference fringe is produced by interference between surfaces (mirror 23 and wafer 1) which are optically conjugate with each other, that an interference fringe is produced under an interference condition established with optical path lengths
25 between points and points upon the optically conjugate surfaces, and that the averaging is accomplished by moving the speckle relative to the fringe through the

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rotary diffusion plate 32.

Figure 7 is a schematic view of a main portion of a second embodiment of the present invention. In Figure 7, like numerals as those of Figure 2 are assigned to corresponding elements.

In this embodiment, there are three lasers having different emission wavelengths. As illustrated, the system comprises a rotary diffusion plate 32, a fiber 7, an illumination system 8, a polarization beam splitter 9, a quarter waveplate 10, a first objective 11, a second objective 13, a CCD camera 14, a quarter waveplate 21, another quarter waveplate 22, a mirror 23, and a shutter 24.

In this embodiment, even if the surface level difference of a mark 2 or 3 to be detected is changed, an appropriate laser may be selected to assure production of a signal of high contrast. If, for example, the surface level difference of the mark 2 or 3 is equal to a product of the illumination wavelength by an integer plus a half wavelength, the interference image is under the same interference condition as of the alignment mark 3 or of the mark 2 outside the mark 3. Thus, the signal contrast is very low.

As a numerical example, it is assumed that the wavelength of the illumination light is 633 nm, and the surface level difference is 950 nm which corresponds to one and a half of the wavelength. This

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is just the condition described above. If, for example, a laser having an emission wavelength 785 nm is used as illumination light, the level difference of 950 nm now corresponds to 1.21λ ($950 = 785 + 165 = 785 + 0.21 \times 785$), such that an interference image of high contrast can be produced.

The number of lasers to be prepared is not limited to three, as in the Figure 7 example. Only two lasers will provide a sufficient result. However, in consideration of complexity in semiconductor processes, many light sources as much as possible may preferably be used. Thus, three lasers are used in this example.

While the present invention has been described with reference to examples where a low image contrast for a small surface level difference in a bright-field detection system is increased significantly, the invention is not limited to it. For example, the invention can be applied to measurement of a mark with a three-dimensional shape, with similar advantageous results.

As shown in Figure 2, both of a He-Ne laser 31 and a halogen lamp 5 may be prepared as light source means, which may be used interchangeably. When the He-Ne laser 31 is used as a light source, measurement of a three-dimensional shape can be performed on the basis of images at four focuses

(images obtainable while changing the focus amount successively, each by a unit $\lambda/4$), that is, measurement can be done in accordance with what is called a fringe scan method.

5 If, on the other hand, the halogen lamp 5 is used, there occurs white interference and thus the coherence length becomes short. Therefore, measurement of a three-dimensional shape on the basis of what is called a coherence probe method.

10 As regards details of the fringe scan method for measurement of a three-dimensional shape, reference may be made to "Needs and Seeds of Optical Measurement", Corona Co., page 228. Also, as regards details of the coherence probe method, reference may
15 be made to "Theory and Practice of Laser Microscopes", page 82, Volume 1 of "New Optical Microscopes", Gakusai-Kikaku Co.

20 Next, an embodiment of a semiconductor device manufacturing method which uses a position detecting system such as described above, will be explained.

Figure 8 is a flow chart of procedure for manufacture of microdevices such as semiconductor chips (e.g. ICs or LSIs), liquid crystal panels or CCDs, for example.

25 Step 1 is a design process for designing a circuit of a semiconductor device. Step 2 is a process for making a mask on the basis of the circuit

pattern design. Step 3 is a process for preparing a wafer by using a material such as silicon. Step 4 is a wafer process (called a pre-process) wherein, by using the so prepared mask and wafer, circuits are practically formed on the wafer through lithography. Step 5 subsequent to this is an assembling step (called a post-process) wherein the wafer having been processed by step 4 is formed into semiconductor chips. This step includes an assembling (dicing and bonding) process and a packaging (chip sealing) process. Step 6 is an inspection step wherein operation check, durability check and so on for the semiconductor devices provided by step 5, are carried out. With these processes, semiconductor devices are completed and they are shipped (step 7).

Figure 9 is a flow chart showing details of the wafer process.

Step 11 is an oxidation process for oxidizing the surface of a wafer. Step 12 is a CVD process for forming an insulating film on the wafer surface. Step 13 is an electrode forming process for forming electrodes upon the wafer by vapor deposition. Step 14 is an ion implanting process for implanting ions to the wafer. Step 15 is a resist process for applying a resist (photosensitive material) to the wafer. Step 16 is an exposure process for printing, by exposure, the circuit pattern of the mask on the wafer through

an exposure apparatus such as described above. The exposure process is performed after a wafer alignment process based on detection of the position of an alignment mark or marks, through a position detecting system described hereinbefore.

Step 17 is a developing process for developing the exposed wafer. Step 18 is an etching process for removing portions other than the developed resist image. Step 19 is a resist separation process for separating the resist material remaining on the wafer after being subjected to the etching process. By repeating these processes, circuit patterns are superposedly formed on the wafer.

With these processes, high density microdevices can be manufactured.

In accordance with the embodiments of the present invention as described hereinbefore, like with a phase difference detecting system, the contrast can be improved while a TIS causal factor is suppressed low, and thus a mark for position detection can be detected stably and with a good precision even in a process of a small surface level difference such as a CMP process. Therefore, the invention can provide a position detecting system and/or an exposure apparatus having the same with which a pattern of a reticle can be transferred onto the surface of a wafer very accurately and precisely.

Further, in accordance with the present invention, an interference microscope system can be used with bright-field illumination, by which a high contrast can be assured for a mark of small surface level difference such as in a CMP process. Thus, high precision position detection can be accomplished.

While the invention has been described with reference to the structures disclosed herein, it is not confined to the details set forth and this application is intended to cover such modifications or changes as may come within the purposes of the improvements or the scope of the following claims.

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